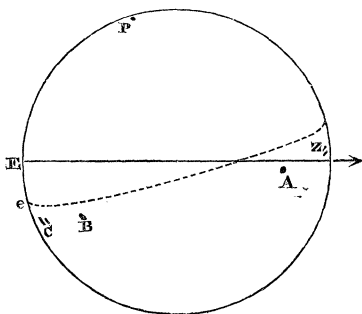


II. "Notice of a Zone of Spots on the Sun." By JOHN PHILLIPS, M.A., LL.D., F.R.S., Professor of Geology in the University of Oxford. Received March 22, 1866.

During the latter half of February and the first half of March, spots of extremely varied character have appeared on the sun, and have been seen with great distinctness, in good observing weather, through the whole or parts of two semi-rotations. On the 13th of February, at 10^h 25^m, four spots were visible on the disk, in the situations marked Z, A, B, C in the diagram No. 1. In that diagram the apparent course of the sun's equator is

Diagram No. 1.



marked by the curved line *e*, and the pole of rotation at *P*. Thus the four spots indicated for observation being all on the same side of the sun's equator, and all within the latitude of 10°, constitute a zone of spots. Since that date a fifth spot, *D*, still in the same zone, has appeared, following *C*. Of these *Z* was about to disappear; its reappearance was noted, and several remarkable changes in form were observed while it traversed half the disk, till its contraction to a black speck 1000 miles in diameter, after which it was obliterated. The spot *B* had advanced some distance on the disk, and was followed till the 21st of February, when it approached the edge, with indications of being a shallow concavity. It was not observed to reappear. The spots *A* and *C* require longer notice, both on account of their persistence through more than a rotation-period, and because of the remarkable changes which they have undergone.

The spot *D* is now under observation.

The spot *A*, visible from the 4th to the 16th of February, and again reappearing early in March, was solitary, and approximately round, measuring, on February 10, about 23,000 miles across the penumbra, and about 8000 across the umbra.

It had a clear brown tint over the whole penumbra, the body of the sun appearing fairly white, and a deeper brown tint over part of the umbra, the remaining and larger space of the umbra being black. The penumbral space was marked with the broken structure represented in a former com-

munication*. The edges of the umbra and penumbra were much broken, the former running out into a sharp point on the apparent left, and including a lighter brown space.

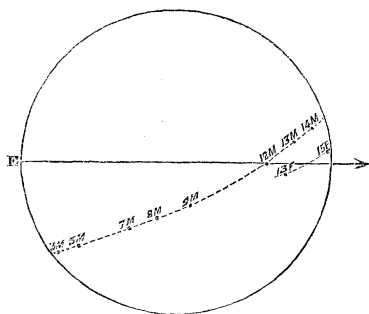
Except in this part, the dark umbra was uniformly and equally distant from the penumbral border, so that it offered an excellent object, large enough and distinct enough to be employed with confidence as a test of the depth of the umbra beneath the luminous photosphere.

In a former communication I assigned to an umbra of good figure, carefully observed, a depth of only 300 miles†. Since then M. Chacornac‡ has given the depth of 400 miles as an approach to average, though in some cases 1000 miles might be nearer. That the spots are most frequently sunk below the photosphere, as Wilson long since asserted, can no longer be doubted, since Mr. De la Rue, Mr. Stewart, and Mr. Loewy have recorded, after many measures of photographs taken at Kew, as the general result that the interior parts of the solar spot are sunk below the general surface§.

The spot now under consideration approached the edge of the disk on the 15th of February, when the umbra seemed nearly bridged across by a lighter part, and was perceptibly but very slightly nearer to the following, or left-hand side.

The reappearance of this spot was anxiously looked for. It came into view on the morning of March 3, having when observed passed the limb about $6^{\circ} 16'$. Its appearance was sketched on this occasion, and again on successive days to the 14th of March. Its apparent magnitude was diminished, but the main features were less altered than is usual with sun-spots. The umbra still appeared in such relation to the penumbral border as to confirm the opinion of its being but very little depressed below the photosphere. Remarkable changes happened between the 7th and 10th of March. On the 8th two broad penumbral extensions appeared; on the 9th these were separated into two detached masses, and much altered in figure.

Diagram No. 2.



The path of spot A in February and March.

* Proc. Roy. Soc. Nov. 23, 1865.

† Ibid. Jan. 26, 1865.

‡ Bull. des Obs. 1865.

§ Researches in Solar Physics, 1865.

The great spot, or rather aggregation of spots, marked C, was observed from the 13th to the 24th of February, as often as good opportunities occurred in the extremely variable weather. When fully expanded, about the 17th, 18th, and 19th of February, it measured about 12° on the surface of the sun, and occupied a space about 100,000 miles long, lying not quite parallel to his equator, and including forty or more black, dark, and dusky umbral tracts, in a complicated penumbral area. The definition was often excellent, so as to show the granular surface of the photosphere with more than ordinary distinctness.

The same fine brown tint already referred to was observed in the penumbral spaces, and there was every gradation of depth in this tint observable in the many specks and spots, till in a few only it seemed to be black. The penumbral tracts were plainly broken up into a kind of network of granulation; and the largest spot, chosen for special study, threw out long black digitations into the surrounding granulated space of the penumbra, like slits in a solid substance, 1000 or 2000 miles in length.

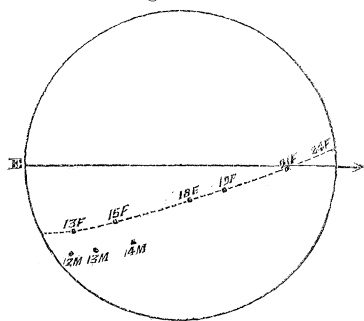
These characters of the largest spot in the group C became very prominent on the 19th of February, and were accompanied by others of an unusual character, which seem to deserve special attention in the question of the nature and history of these black spaces. In the drawing for this date these appearances are sketched with a power of 135. The spot was somewhat rhomboidal, the extreme length from angle to angle being about 15,000 miles, the least breadth about 4500. On the right the boundary was gently convex; parallel to it was a bright facular tract of uniform breadth; this was margined on the right by a nearly continuous very narrow black band, 17,500 miles long, extending in both directions beyond the spot, and slightly ramose in the (apparently) upper part. Parallel to this again was a curiously interrupted series of black angularly bent sharp cuts, ending upwards in a larger subdigitated mass, near which were some other small spots, forming broken chains, which turned off in curves to the right for about 40,000 miles (Pl. II. fig. 7).

On the 20th of February the appearances had changed to those represented in another sketch (Pl. II. fig. 8), where the great spot, something reduced in magnitude and altered in figure, shows very long digitations on all sides; the facular space on the right is broader; the long very narrow black band shows two internal extensions; the outer crested ridge has gathered itself into a shorter figure, 10,000 miles long, and has lost the character of angular tegulation which was so remarkable on the 19th.

On the 21st the spot had approached enough toward the limb to undergo some apparent change of general figure, by contraction perpendicular to the edge; the facular space on the right was entirely free from the narrow curved black divisional band; and the summit of the outer broader band was bent away from the great spot, to which it had been parallel (Pl. II. fig. 9). The disappearance of the spot amidst large elevated bright faculæ and depressed broader shaded tracts, was sketched on the

24th of February. Reappearing with similar splendid companion ridges of mountainous clouds, but much reduced in size, and altered in every part, it was observed again from the 12th to the 17th of March, after which the weather allowed no further opportunity. Two sets of drawings of this remarkable spot are presented to show its growth, development, and decay (Pl. II. figs. 7, 8, 9, and 10, 11, 12). The apparent path on the sun's disk is given for each period of appearance—the two paths differing by reason of the change in the apparent place of the sun's equator (see Diagram No. 3).

Diagram No. 3.



But few examples occur of such large penumbral tracts grouped about so many dark and half-darkened umbræ. On the sun they occupied, as already stated, a tract about 12° in length, not quite parallel to the equator; and may be compared to some of those which are most conspicuous in Mr. Carrington's plates.

From what has been observed, it appears that, in a given zone of spots, not only are the aspects of the particular spots much diversified, but further, that the changes to which they are subject offer much variety. These circumstances seem to point to particular local conditions as the cause of the diversity of appearance, though it may be possible to refer to other influences the frequency of their occurrence, if not the fact of their occurring at all.

The five spots now under review lie within an arc of longitude of 205° , leaving 155° in which as yet no spot has lately been seen. In 1864, during the months of March and April, a zone of spots, also five in number, and on the same side of the equator, was contained within an arc of longitude of 243° , leaving 117° at that time free from spots. There was then within the same arc of 243° a pair of spots in about the same latitude, but in the opposite hemisphere. Taking these into account, the average of the arcs of longitude between the spots was about 49° . In the case of the spots lately passing it was 51° . Twenty-six revolutions would have brought the middle of that zone of activity of 1864 to nearly the same place on the sun's disk, as the group now under consideration.

To whatever cause we may ascribe the fact of the breaking out of these

spots, there would appear reason for expectation that spots of like character may be expected to recur again in the same parts of the sun's surface. In the great work of Mr. Carrington we find several examples of the appearance of new spots in nearly the same places as those which had been so occupied before. Those who think with M. Chacornac that sun-spots are due to volcanic eruptions, and regard their changes of appearance as effects of the displacement of solid and gaseous bodies about the region of disturbance, must naturally look for repetitions of these phenomena in the same parts of the solar surface.

The greater frequency of spots between the parallels of 10° and 30° lat. N. and S., the comparative rarity of them on the equator, and the almost entire absence of them from the circumpolar regions is well established. If we take the data from Mr. Carrington's register and suppose in all 1000 spots to be observed, 178 will be found between the parallels of 0° and 10° from the equator, 450 between 10° and 20° , 324 between 20° and 30° , and 48 above 30° .

The proportionate numbers for the northern and southern hemispheres are 450 in North latitude, 550 in South latitude.

If now we inquire, by the aid of the same invaluable book, as to the relative frequency of spots in different longitudes, we shall obtain a result of considerable interest in reference to the question of the place of the eruptions. Mr. Carrington has registered his observations through 99 rotations, and has arranged them in groups which can be tabulated for longitude. Assuming the rotation-period to be exact enough for fixing the longitudes in the course of seven years and 142 days, we may represent the relative frequency of the spots on different meridians as follows:—

Longitude	10° to 20°		320 maximum ;
„	60 to 70		220 minimum ;
„	100 to 110		313 maximum ;
„	160 to 170		250 minimum ;
„	190 to 200		366 maximum ;
„	300 to 310		173 minimum ;

showing three maxima at intervals of 90° , 90° , and 180° , and three minima at intervals of 100° , 140° , and 120° . Or if we take the circumference of the sun in three meridional compartments of 120° each, and suppose 1000 spots in all, we shall find

0 to 120		357
120 to 240		368
240 to 360		274

I am at present of opinion that this result may be trusted so far as to show that certain tracts of the sun's surface are more liable to eruption than other tracts, by reason of local peculiarity only.

Luminosity of the Sun.

Attentive observation shows the light of the sun to be feeblest toward the edges of the disk, strongest about the centre. By M. Chacornac's measure the ratio of the central to the marginal light is 100 to 45. Looking directly on the central regions, the light is found to be much the brightest on the apparent summits of the undulations of the photosphere ("rice-grains"); and looking to the limb, it is the faculæ which are the brightest parts. In each case it is the outermost parts of the photosphere which are the brightest, and it is the innermost parts which are the darkest. The depth of shade appears to be in direct proportion to the depth below the outer surface of the photosphere. It appears to me that such appearances would follow naturally from the hypothesis mentioned in my first communication on this subject*. The hypothesis is that the lowest parts of the umbral spaces yield the least refrangible and least luminous rays, such as belong to the space about the red end of the spectrum. These spaces may not be black, not even very dark, except by comparison with the brilliant spaces around; where the rays from them pass into the photosphere, they heat it, as the dark rays separated by sulphuret of carbon in Tyndall's experiment heat the platinum foil, and other solid bodies. Bodies thus heated emit new rays according to their nature; the solar photosphere is of such a nature as to send to us the mingled pencils which we receive; the principal effect of this kind being at a maximum on the outermost layer. The effect of this will be to cause streams of the most luminous rays from the most elevated parts of the photosphere, which will be seen directly in front, about the sun's centre, while toward the edges the sides of the undulations alone will be seen, and the rays which they yield will be less luminous—the only parts which are *there* very bright being the high ridges of the faculæ.

Another view has presented itself to me. If we admit the depressed part to be the body of the sun disclosed from below the luminous envelope, we may suppose its darkness to be due simply to radiation. For however hot the sun may be, if its composition be like that of the earth, the fused parts would be cooled and darkened at the surface where it may be uncovered—very much darkened where the exposure is complete (the umbra), partially so where the envelope is not wholly removed (the penumbra). It might be some test of this view, if the hourly changes of the umbra, immediately after its first appearance, could be accurately noted in respect of the degree of darkness as well as of the change of form. The umbra ought to grow darker and darker, never lighter and lighter, except by the overspreading of photosphere, which would be indicated independently by changes on the penumbral area.

From what I have seen in the course of these observations, I infer that the study of the physical condition of the solar spots cannot be regarded as likely to yield data of sufficient weight, if it do not include determina-

* Proc. Roy. Soc. January 1865.

tions at short intervals, as twice a day for the whole penumbral outline, and once an hour for selected critical parts of the umbra.

EXPLANATION OF PLATE II.

[The figures are all drawn to represent the objects as they appeared in a 6-inch achromatic furnished with the glass mirror set to reflect the rays in the equatorial plane to the westward. The motion of the spot is from left to right.]

- Fig. 1. Appearance of the spot A, nearly on the central meridian, on Feb. 10th, 1866, at 11^h 15^m. The darkest part of the umbra was to the right; on the left a sharp excurrent part like a fissure; between this and the larger and darker part was a lighter brown tract. Small dots on the penumbra in the upper part to the left. Diameter 23,000 miles.
- Fig. 2. First sketch of the spot A after its reappearance, March 5th, 10^h 30^m. The long excurrent parts at the extremities of the elliptical figure (elliptical by reason of the proximity of the spot to the edge of the disk) are frequent appearances in this position of the spots. This figure is rather too small in proportion to 4, 5, and 6.
- Fig. 3. Spot A, further on the disk. The figure is rather too small. Note the peculiar shapes of the small fissure-like extensions on the left. March 6th, 2^h 30^m.
- Fig. 4. Spot A, still further on the disk, March 7th, 10^h 0^m. The ramifications from the umbra have changed in appearance.
- Fig. 5. Spot A, near the central meridian, March 8th, 12^h 30^m. The two extensions of the penumbra on the left have come into sight since yesterday. Note the little dot at their common origin, and, directed towards it, the longest of the excurrent umbra fissures.
- Fig. 6. Spot A, March 9th, 12^h 0^m. Here the excurrent penumbral tracts are found to be separated from the spot, and from each other, and changed in direction. The umbra is much altered, and has a deep emargination, in place, apparently, of a small white speck, seen in fig. 5. Note also a black speck on the right upper edge of the umbra.
- Fig. 7. Spot C, the largest umbral tract with its border on the right, Feb. 19th, 10^h 45^m. On account of the remarkable aspect which the umbra wore on this occasion, it was drawn repeatedly with great care. Note in particular the digitations of the large umbra, the broad facular space to the right, and the parallel very narrow, interrupted, and tegulated umbral bands, which are part of a system of interrupted small dark tracts, traceable through nearly all the length of the penumbra, which on this occasion was about 100,000 miles from end to end. The umbra itself measured about 15,000 miles between the extremities of the digitations.
- Fig. 8. The same parts as they appeared on Feb. 20th, 10^h 20^m. The general figure of the umbra is changed; the long parallel narrow black space, and the broader tract on the outside of it are greatly altered; the latter, turning away from the umbra, appears to have gathered into itself the detached spots which appear in fig. 7, and to have lost the angular tegulation which then was conspicuous.
- Fig. 9. In this figure the approach toward the edge of the sun is sensible in the elongation of the large umbra and its companion. Feb. 21st, 2^h 30^m.
- Fig. 10 shows the reappearance of this spot C, near the edge, with a divided umbral tract, of different shades of darkness; the whole figure compressed elliptically by proximity to the edge. March 12th, 12^h 10^m.

Fig. 11. The same spot after it had proceeded on the disk, so as to allow of all parts being seen in their true proportions. March 13th, 2^h 30^m. The change of figure in the whole penumbral space, and in the darkest parts, is so great that it is difficult to be assured of the identity of any one point now visible with the appearance shown on any occasion in February. Yet, in fact, on searching carefully the neighbouring tracts of photosphere, we can discern what appear to be traces of the spaces occupied by the old penumbra. This important observation was made, not by myself only, but also by friends who were quite unaware of the interesting changes of form which had occurred.

Fig. 12. March 14th, 11^h 30^m. Here the spot is seen further modified; gathered up into a smaller and more regular shape, with a deep slit through the penumbra into the umbra; the detached penumbra on the left was lost after a further day's motion.

The Society then adjourned over the Easter Vacation to Thursday, April 12.

